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SEMIANNUAL PROGRESS REPORT

on

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Under NASA Research Grant No. NsG-110-61 research to establish methods of structural synthesis has been underway since December 1, 1960 at Case Institute of Technology. The objective of the Structural Synthesis Research Program is to bring an ever more meaningful class of design problems within the grasp of rational and directed optimization in terms of realistic criteria. A governing technology which can be used to predict the behavior of a proposed design is a prerequisite to undertaking the automated optimum design task. The range of technologies on which synthesis capabilities are being built has broadened considerably since the inception of this research program in 1960. At the outset these synthesis investigations were limited to structural systems where linear structural analysis and elastic stability analysis constituted an adequate technology. More recently the synthesis concept has been applied to systems with governing technologies such as dynamics, aeroelasticity, thermoelasticity, nonlinear structural analysis, and structural reliability analysis. The synthesis activity is viewed as a component within the broader framework of engineering design. Within the hierarchy of decisions which make up the design process it is important to distinguish between

(1) the conceptual level of design which is inherently creative

(2) the computer aided design level employing the man-machine interaction approach and characterized by qualitative judgements based on externally displayed quantitative information

(3) the automated optimum design level employing the engineering synthesis approach and characterized by logical decisions based on internally stored quantitative information.

The structural synthesis research program seeks to advance the level in the hierarchy of design decisions where strictly logical decision making processes may be fruitfully employed.

The goal of advancing synthesis capabilities so that the concept can be used to achieve superior designs for actual systems as soon as possible is being pursued by a broad attack involving projects in four main categories:

(A) The study of additional elementary systems.

(B) The study of the interrelation between design philosophies, synthesis and analysis.

(C) The development of operational synthesis capabilities for certain general problem classes.

(D) The exploration and evaluation of synthesis techniques.

(A1) An exploratory application of the synthesis concept to the optimum design of a double wedge airfoil where the governing technology is aeroelasticity has been successfully completed. The criterion function employed in this study is the total energy required to drive the airfoil through a sequence of flight conditions. The synthesis problem is to minimize this total energy function subject to limitations on the wing tip deflection, root stress, angle of attack, and weight as well as a constraint preventing flutter. The results obtained to date are being revised to include the influence of hollowing out the wing as well as adding the wing weight to the lift required in each load condition. A trade off study is planned in which the energy penalty is determined as the maximum permissable wing weight is systematically lowered. An EDC report on this work is in preparation.

(A2) An exploratory application of the synthesis concept to the minimum weight design of a three layer heat shield has been completed. The design variables in this problem are the thickness and density of each layer of the shield. The behavior variables are taken to be the temperature responses to the various heat flux load conditions and the stress response to the innermost layer. The thermoelastic analysis on which the synthesis is based includes temperature dependent material properties and reradiation from the exposed surface. Synthesis results have been obtained and it is interesting to note that distinct optimum designs of essentially the same weight have been obtained. This suggests the possibility of a pseudo-design variable such as was previous encountered in Ref. 1.

(A3) An extension of the shock isolator synthesis capability previously reported (Ref. 2) has been undertaken. The extension will include nonlinear but conservative behavior of the spring and time dependent damping. The goal of this study is to devise a means for automatically determining the best form of the force deformation relation for the spring in conjunction with a feed forward damping strategy. Minimization of the maximum acceleration subject to displacement limits and minimization of the displacement subject to acceleration limits will both be considered. It is also envisioned that side constraints on the damping coefficient and its time rate of change will be included. This study is aimed at exploring the importance of considering static and dynamic design variables simultaneously.

(B1) The integrated analysis-synthesis concept is being studied in greater depth. The basic ideas and some preliminary results obtained with this approach were reported at the AIAA 5th Annual Structures and Materials Conference (Ref. 3). These preliminary results were encouraging and effort is currently being directed toward developing a minimum weight synthesis capability based on the integrated approach for a generalized space truss. The design variables will be the diameter and wall thickness of the annular cross section for each member in the system. In addition to the usual stress and displacement limits on the behavior provision will be made to include constraints against tangent modulus buckling and local crippling. Geometric nonlinearities are not included in the analysis but conservative material nonlinearity is included on an optional basis. The central purpose of this study is to evaluate the potential of the integrated approach as a means of synthesis for large structural systems. An attempt to extend the integrated analysis synthesis to dynamics problems of the shock and vibration isolator type has encountered difficulties. Modifications or adaptations which may overcome the present difficulties will be sought.

(B2) A study is being made with the aim of conducting structural synthesis within the framework of a reliability based design philosophy. Effort has been directed towards finding the over-all structural reliability of an indeterminate structure in which it is necessary to consider both independent and dependent failure modes. Other studies to date have assumed that all failure modes are independent and are thus led to excessive design

weight. In finding the over-all reliability, the conditional probability of different members failing under the same environmental loading and the conditional probability of a single member under different environmental loadings must be computed. The probability of failure of a structural component has received exhaustive attention in the literature but the problem of over-all structural reliability is a new undertaking. Results thus far indicate that a linear perturbation method can be used to rapidly compute the conditional probabilities. The accuracy obtained should be adequate for engineering usage and consistent with the precision of available input data. These results will be checked by an existing program which utilizes the Monte Carlo Method for computing the reliability. The incorporation of the linear perturbation method into existing synthesis capabilities will be studied during the next report period.

(C1) A first attempt at developing a synthesis capability for a class of plate and shell type structures has been completed and tested. The analysis component of this capability was tested on the following structural systems:

1. Flat cantilever membrane subject to an inplane distributed load.
2. Square cantilever plate subject to a single concentrated load (linear and nonlinear solutions)
3. Isotropic cylinder subject to a pinching load.
4. Square fixed edge isotropic plate subject to a high intensity distributed pressure. (linear and nonlinear solutions)

5. Orthotropic cone subject to internal axisymmetric and nonaxisymmetric loads.

In all of the above test cases, the results correlated sufficiently well to conclude that the analysis program was functioning properly. Several analysis shortcomings were uncovered by these cases. Nevertheless, the analysis capability was thought to be sufficiently accurate, versatile and representative of the state of the art to warrant the development of an associated synthesis program. The synthesis program was designed to achieve a maximum savings in weight during the early stages of redesign by avoiding constraint surfaces. This early stage efficiency was sought because of the large amounts of computer time consumed during a single analysis cycle. As the current design evolves toward the optimum design, the efficiency drops off because the method of operation approaches the more conventional methods of steepest descent.

The following is a list of the test cases used to test the synthesis capability:

1. A four bay flat cantilever subject to a line load (4 design parameters)
2. Waffle plate subject to a membrane load (3 design parameters)
3. Sandwich cylinder subject to a multiplicity of 3 load conditions (3 design parameters)

Case 1 converged to a solution which can be deduced as the optimum design. Case 2 converged to a solution comparable to that presented in Ref. 4. Case 3 converged to a solution where over half of the behavior variables were constrained. It is thought that the synthesis program is capable of handling upwards of (20) design parameters (the program maximum capability based on storage capacity is 80).

The amount of time consumed in the redesign portion of the cycle is very small compared to the analysis cycle. An EDC report on this work is in preparation.

(D1) An investigation aimed at making use of existing and recently reported techniques from the mathematical programming area is under way. A study of the member sizing problem for a general space truss without buckling constraints has been made. It was possible to decompose this problem in such a way as to make use of the concepts of linear programming to prove that the minimum weight design for a single load condition case is statically determinate even in the case where the truss is subject to deflection limits. Another facet of this work involves the exploration of a method for solving the synthesis problem which is based on the repeated application of linear programming methods to linearized approximations of the actual nonlinear programming problem. Renewed interest in this approach is a result of viewing the synthesis problem in the integrated space as distinct from the design variable space. In addition to this, consideration is being given to various ways of breaking down large structural synthesis problems in several interrelated but smaller optimization problems. This process replaces the large nonlinear programming problem with several smaller ones which are coupled together. From the point of view of effort needed to obtain a solution the advantage of solving several smaller problems repeatedly, as opposed to solving the original large problem once, requires evaluation.

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